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THE IRON-FORMATION ON BELCHER ISLANDS, HUDSON BAY, WITH SPECIAL REFERENCE TO ITS ORIGIN AND ITS ASSOCIATED ALGAL LIMESTONES

E. S. MOORE
Pennsylvania State College

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LOCATION AND AREA OF THE ISLANDS

The Belcher Islands have been until recently but little known outside of Hudson Bay, although for decades considerable trade has been carried on between the trading-posts on the bay and the Eskimos living on these islands. On most modern maps the "North Belchers" and "South Belchers" are indicated by small dots, while one chart shows a sounding of several fathoms which would probably fall on the main island. The old map prepared from Sir Henry Hudson's notes is more nearly correct in indicating the size of this land mass than any which has since been published.

These islands recently have been brought to the attention of the public through the work of the Sir William Mackenzie Expedition to Hudson Bay and Straits. This expedition was in charge of Mr. R. J. Flaherty, and to him credit is due for the accompanying outline map (Fig. 1), as minor changes only have been made in his original copy. Although this map is the result of a reconnaissance survey, it serves as a basis for travel and outlines the larger features of the land masses.

On account of the discovery, by Mr. Flaherty, of large bodies of jasper, the writer visited the islands in the summer of 1916 for the purpose of reporting on the commercial value of the iron deposits. This is believed to have been the first visit to this district by a geologist, and it is owing to the kindness of Sir William Mackenzie, who has granted permission to publish it, that this geological report is presented.

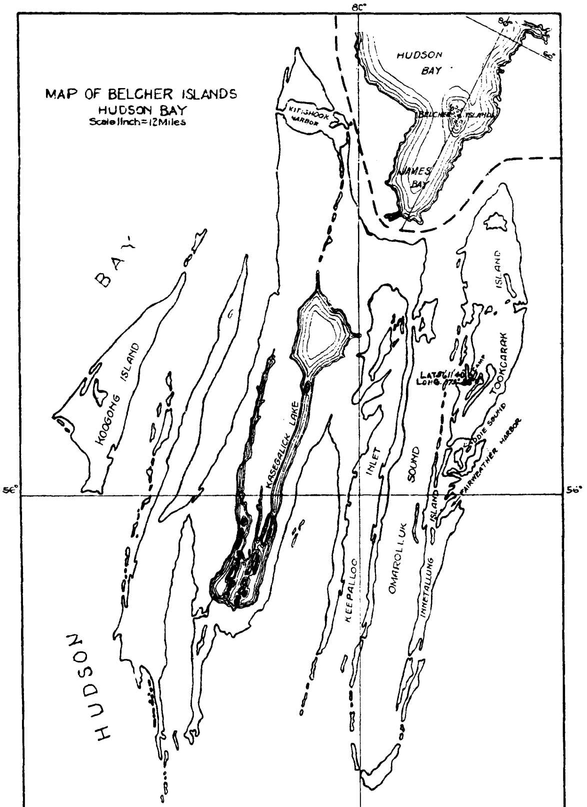

FIG. 1.—Outline map of the Belcher Islands, Hudson Bay

The Belchers, which contain a number of large islands, apparently form one large group rather than two small ones. The group is over ninety miles long and nearly sixty miles broad, and its eastern border lies about seventy miles northwestward from the mouth of

Great Whale River, on the southeast coast of Hudson Bay. Its latitude and longitude, as indicated on the outline map, were determined from astronomic observations made by Mr. Howard, a surveyor accompanying the expedition. There would be many good harbors on the islands if the bays and sounds were charted.

TOPOGRAPHY

The main physiographic features of these islands are long, narrow, more or less rounded ridges separated by sounds which are in few places more than two or three miles wide. These linear features are due to the fact that the islands are made up of a folded series of igneous and sedimentary rocks which have weathered so that the sea has entered upon the land where the less resistant beds have been eroded away. The relief, as in most other pre-Cambrian regions, is not great, the highest point so far recognized being only 450 feet above sea-level. This point is located on the large basalt hill near the center of Tookcarak Island. Few elevations have an altitude of more than 250 feet, and the land presents a worn, glaciated surface, in most places absolutely devoid of vegetation and entirely without trees. This lack of vegetation on all surfaces except on low, drift-covered areas seems to be due, not only to a complete scouring of the rocks in Pleistocene time, thus removing all soil, but also to the ice which forms on these rocks during the severe winters of the present day. There must be considerable local slipping of ice over these smooth rocks when the spring thaws come.

The occurrence of poorly developed gravel and bowlder beaches, which seem to reach as high as the highest point on the islands, is an interesting relic of Pleistocene time. It is probable that the Belchers were completely submerged during the period following the ice invasion and before the uplift of the whole Labrador Peninsula.

A rather peculiar topographic feature was observed on the basalt hill on Tookcarak Island. On this hill piles of rock were found, varying from 3 to 8 feet in height and from 7 to 15 feet in diameter. These piles are roughly conical in shape, with a depression in the top, and their shape first suggested a possible artificial origin—some sort of mound constructed by natives. However, the finding of the fragments of a quartz vein, which had cut the basalt strewn across the pile in a straight line, showed that without doubt the blocks had been heaved up by the frost. The hollow in the top is due to the expansion of the ice forming in the depression, thus crowding the rock outward and upward.

GEOLOGICAL FORMATIONS

The islands are made up of a thick series of interbedded igneous rocks and sediments. To the group of sediments the name Belcher series has been applied, and the igneous rocks have been designated the Tookcarak diabase and basalt because of the fine exposures of these rocks on the island of that name.

There is a close relationship between these formations and those on the Nastapoka Islands and in Richmond Gulf, already described by Low[1] and Leith,[2] and they represent deposits of the same system made farther offshore. There is also a very marked resemblance between them and the Animikie and Keweenawan formations of the Lake Superior region. The following stratigraphic section may be taken as typical of the thickness and character of the Belcher series and the associated igneous rocks in the eastern part of the islands:

		FEET
1.	Flow of basalt, ellipsoidal and amygdaloidal	230+
2.	Iron-formation consisting of jaspilite, chert, cherty-iron-carbonate, greenalite, hematite, magnetite, and shale	450
3.	Pink, white, and gray coarse-grained quartzite with bands of coarse brown sandstone and arenaceous limestone	512
4.	Coarse brown sandstone and arenaceous limestone interbedded with pink and white quartzite grading into bands of gray schist and slate	2,394
5.	Diabase sill	8
6.	Gray, green, red, and white very distinctly banded slate and shale varying from calcareous to siliceous and locally containing perhaps 25 per cent of iron	910

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[1] A. P. Low, "Geology and Physical Character of the Nastapoka Islands, Hudson Bay," *Ann. Rept. Geol. Surv. of Canada*, XIII (1903), Part DD.

[2] C. K. Leith, "An Algonkian Basin in Hudson Bay," *Economic Geology*, V (1910), 227-46.

		FEET
7.	Whitish to brownish calcareous quartzite varying from very fine-grained and cherty to coarse-grained, and grading into black quartzitic slate near the diabase	477
8.	Diabase sill	80
9.	Interbedded, dark, slaty quartzite, graywacke and shale containing considerable lime and usually highly silicified	352
10.	Silicified, crystalline limestone and dolomite interbedded with bands of calcareous red shale	151
11.	Thin-bedded, "ribboned" shales, highly banded in red, white, and gray. These are not uniformly siliceous, and they weather so as to produce striking corrugated surfaces	89
12.	Diabase dike	12
13.	Calcareous and siliceous slate	25
14.	Algal, concretionary limestone silicified and marbleized	428
15.	Diabase sill carrying much disseminated pyrite	190
16.	Mostly drift-covered, but outcrops show dense, gray, banded, siliceous, impure limestone and dolomite altered to talcose schist and serpentine near diabase	2,673
17.	Reddish to gray graywacke and arkose with narrow bands of jasper, shale, and sandstone	618
18.	Great mass of basalt and diabase forming the central mass of Tookcarak Island. The lowest rock recognized in the region and its thickness is uncertain, although it must be considerable. It is not certain whether it is an intrusion or a flow interbedded with the sediments	(?)
	Total thickness of the section	9,599+
	Total thickness of the Belcher sedimentary series	9,079+

The formations of this series, which can be correlated with some degree of accuracy with those of the Nastapoka and Richmond groups, are the iron-formation and the algal limestones. In the section on the Nastapoka Islands, Low does not recognize an erosion unconformity, while Leith considers that there is one between the Nastapoka and Richmond groups. In the section given above, the Richmond group is but poorly represented, but from Leith's description it would appear that the dividing line should be drawn at the bottom of division No. 16. The only evidence of an unconformity observed by the writer was in a narrow band, of about five feet, of fine-grained conglomerate and coarse sandstone containing little fragments of chert and jasper. This is near the base of the algal limestones on the east side of the diabase on Tookcarak Island.

This algal limestone is also well exposed on the mainland just north of the mouth of Great Whale River, where it lies directly on the Laurentian granites.

GEOLOGICAL STRUCTURE

The structure of the islands is, on the whole, simple. The rocks have been folded into large pitching anticlines and synclines, with dips varying from 75° to almost zero and with comparatively few minor folds. The heavy, igneous flows and sills have had some influence on the control of the structure, as seen in the accompanying structure section (Fig. 2). The general strike is nearly north and south, showing that these rocks were squeezed up against the land mass along the eastern side of the basin in which they were deposited, probably because of a settling of the central portion of the Hudson Bay basin. They are more steeply folded than the rocks which occur along the coast of Hudson Bay, from Cape Jones beyond Richmond Gulf, and which form the chain of islands skirting the shore in that region.

THE IGNEOUS ROCKS

The Tookcarak diabase and basalt bear a remarkable resemblance to the Keweenawan basic rocks of the Lake Superior region. Like those rocks, they are extremely monotonous in texture and composition. In some places they carry an abundance of pyrite, and

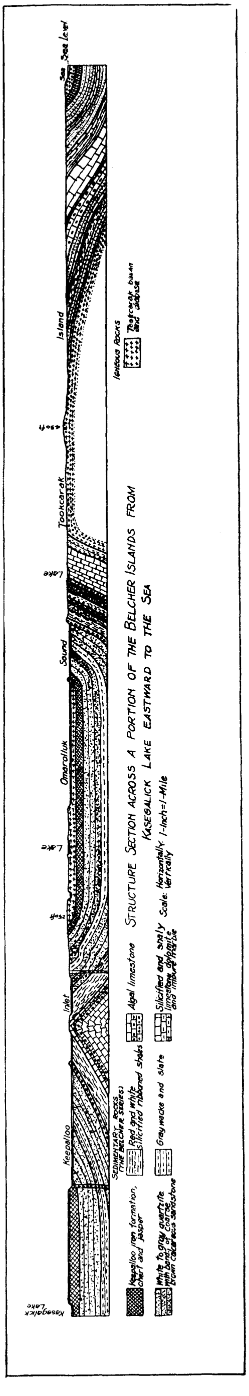
Kasegalick Lake
Keepalloo
Inlet
Lake
Omarolluk
Lake
Sound
Lake
Tookcarak
Lake
Island
Sea level
STRUCTURE SECTION ACROSS A PORTION OF THE BELCHER ISLANDS FROM KASEGALICK LAKE EASTWARD TO THE SEA
SEDIMENTARY ROCKS (THE BELCHER SERIES)
Keepalloo iron formation, chert and jasper
White to gray quartzite with bands of coarse brown calcareous sandstone
Red and white silicified ribboned shales
Graywacke and slate
Algal limestone
Silicified and shaly limestone, dolomite and impure marble
Scale: Horizontally 1-inch=1-Mile Vertically
IGNEOUS ROCKS
Tookcarak basalt and diabase

FIG. 2.—Geological structure section across a portion of the Belcher Islands

more rarely chalcopyrite is found. In one large sill a mass of impure dolomite has been inclosed, partly altered to talc and serpentine and impregnated with chalcopyrite. There is not sufficient copper, however, to be of economic interest.

The occurrence of cobalt in a calcite vein in one of these sills is interesting because of its frequent association with the Keweenawan diabases in other parts of Canada. A narrow vein of calcite was found cutting the basalt and carrying smaltite, chalcopyrite, magnetite, actinolite, and specular hematite.

The relation between the igneous rocks and the sediments is not always clear. In most cases it is quite evident that the former are distinctly later than the latter, but in the case of the large mass of diabase and basalt forming the backbone of Tookcarak Island the evidence is inconclusive. It would appear that the sediments above it have been metamorphosed to some extent, but this cannot be proved to be the result of contact action.

There are some amygdules of chlorite in its upper portion, but no sign was seen of ellipsoids, so common in some of the distinct flows in the area. Although amygdules are usually considered evidence of extrusion, they cannot be taken as definite evidence of such origin because vesicular dikes and sills are known which must have solidified thousands of feet below the surface. The question of whether an intrusive rock will be amygdaloidal or not depends chiefly upon the porosity of the rock adjoining it, and on the amount and pressure of the gases which it contains. Leith regards some of the sheets in the Richmond Gulf region as flows, but so far the writer has not found any of these interbedded igneous masses which he is sure are flows. There is one great extrusion, however, which is the youngest consolidated rock seen on the Belcher Islands, and which apparently at one time spread over the whole of the islands. It seems probable that it also extended to the Manitounick Islands near the coast of the bay. It immediately overlies the main band of iron-formation at almost every point where it outcrops. Its thickness is uncertain, since the flow is largely under water, but it is doubtless several hundred feet. Near Kasegalick Lake it is about 30 feet, but this does not represent its maximum thickness, since it has suffered much from erosion (Figs. 3, 4, 5). This extrusive mass consists of more than one flow, because in some places the surface of contact between two flows may be traced for a long distance (Fig. 6). Ellipsoidal and amygdaloidal structures are

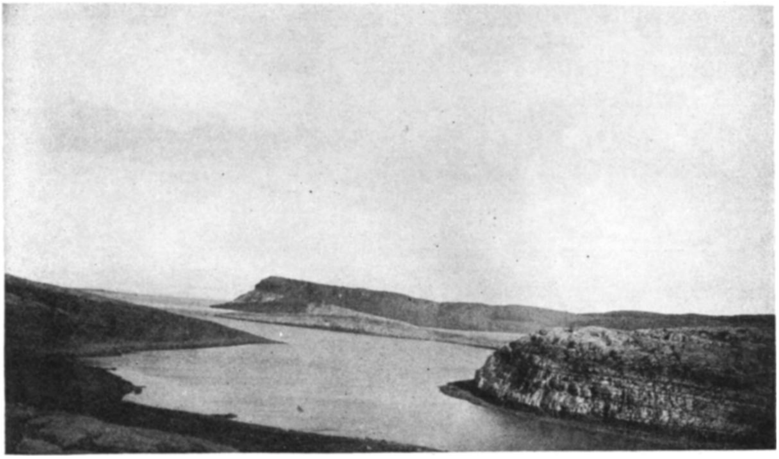

FIG. 3.—View of Innetallung Island showing in the foreground the limestones and quartzites and in the distance the white quartzite overlain by the iron-formation and it in turn by the great basalt flow.

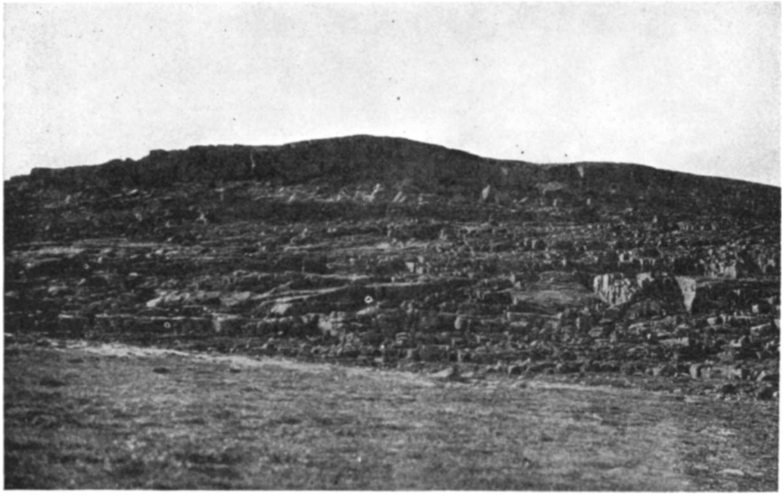

FIG. 4.—The great basalt flow overlying cherty shales and jaspilite on the shore of Kasegalick Lake.

well developed at almost every place where the surface of the basalt is exposed (Fig. 7). Outside of these two bodies all the igneous rock seen showed definite evidence of intrusive origin.

There does not appear to be any definite relation between the origin of the iron-formation and these igneous rocks, because it does not seem to matter whether they intrude it or are flows overlying it, whether they are close to it or are far removed from it. There is in many places a little micaceous and specular hematite near the contact between the diabase and the adjacent sediments, but this seems to be independent of the original iron-formation.

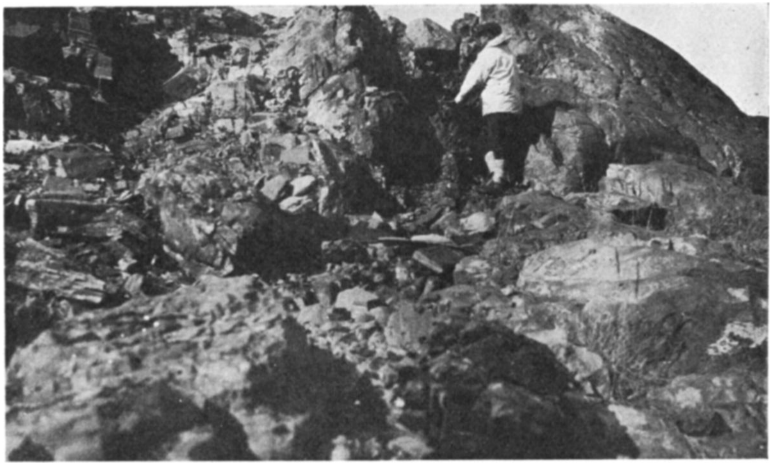

FIG. 5.—Large diabase dike cutting the jaspilite near Kasegalick Lake. It apparently served as a feeder for the large flow shown in Fig. 4, since the flow lies over the jaspilite just beyond the upper left-hand corner of the picture.

THE ALGAL CONCRETIONARY LIMESTONES

In recent years much attention has been paid to the study of the minute organisms which play an important rôle as precipitating agents in calcareous and iron-bearing solutions. It has been proved that low forms of plants, chiefly the algae, are at the present day causing to be precipitated great quantities of calcium carbonate in streams, lakes, and seas, and that the iron bacteria are responsible for the deposition of much iron in bogs and other bodies of water. Dr. Walcott set a new record when he described the numerous algal structures from the pre-Cambrian rocks of Montana,[1] and it now seems certain that these low forms of life flourished well back into pre-Cambrian time, and that they were responsible for the precipitation of large bodies of calcareous matter whose origin was formerly a matter of doubt.

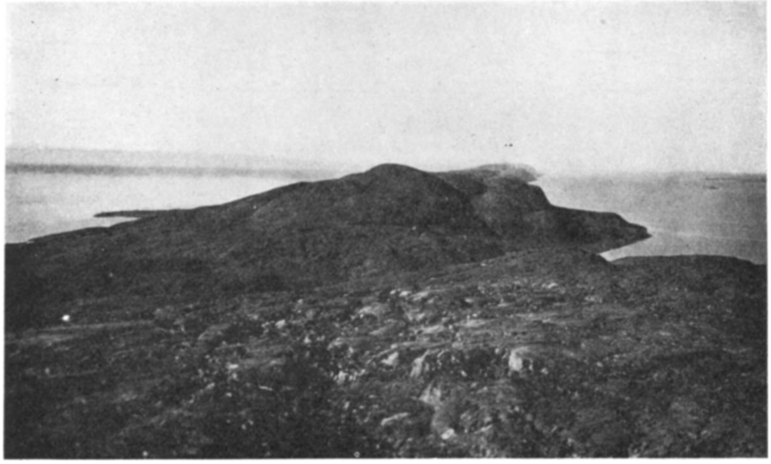

FIG. 6.—The great basalt flows forming Keepalloo Peninsula. The contact between two thick flows may be seen near the foot of the hump in the center of the photograph.

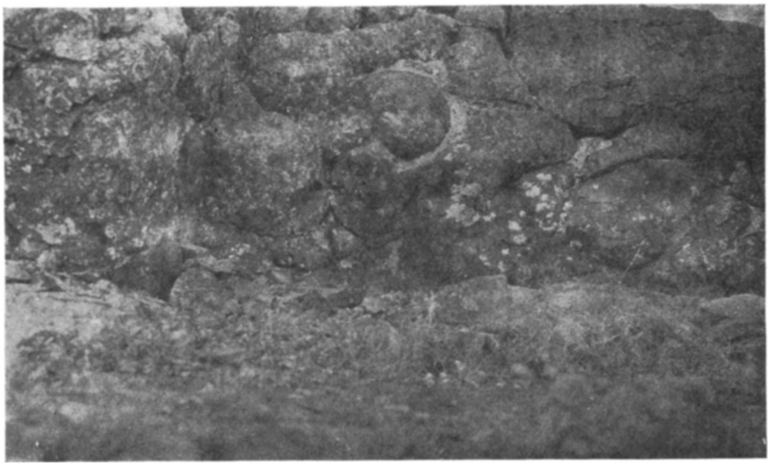

FIG. 7.—Ellipsoidal structure which is very common in the basalt flows

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[1] C. D. Walcott, "Pre-Cambrian Algonkian Algal Flora," *Smithsonian Miscellaneous Collections*, Publication No. 2271 (July 22, 1914), pp. 77–156, Pls. 4–23.

On visiting the Belcher Islands the writer was impressed by the extraordinary development of structures which seemed to resemble so strongly the cryptozoons of the Upper Cambrian that they were at first regarded as species of that fossil. However, there seemed to be some marked differences between the two types, and the Belcher Islands specimens should be regarded as deposits made by a new group of algae. These fossils have an important bearing on the age of the associated rocks, because if they be regarded as cryptozoons we must either change the generally accepted conclusion that these rocks are pre-Cambrian or we must push the cryptozoons back into the pre-Cambrian. There is no definite evidence that the sediments on the east coast of Hudson Bay are pre-Cambrian, but there is as much evidence as there is for the age determination of most of our pre-Cambrian rocks of Northern Canada. Leith[1] points out the remarkable resemblance between them and the Animikie of the Lake Superior region, and Low,[2] after considering them as Cambrian and then as Laurentian, finally concluded that they were more like the later pre-Cambrian.

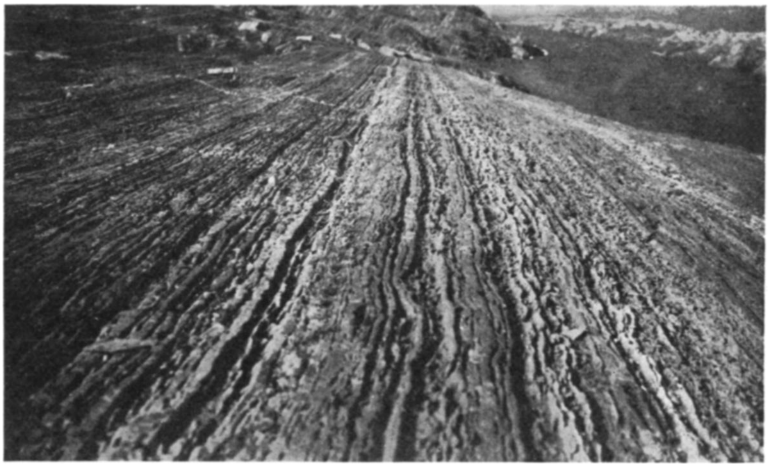

FIG. 8.—"Ribboned" ferruginous shale more highly silicified in alternate layers, Tookcarak Island.

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[1] C. K. Leith, *op. cit.*, p. 233.

[2] A. P. Low, *op. cit.*

Low had observed the concretionary structures mentioned above, and he states regarding the rocks associated with them: "No fossils have as yet been discovered in any of the beds of this formation, but the presence of certain concretionary forms in its limestones and the amount of carbon in many of the shales lead to the belief that at least low forms of life existed at the time these rocks were deposited."[1] Leith also mentions them, in the Richmond Gulf region, as follows: "The limestone floor has great concretionary structures up to two feet in diameter, the sides of the concretions locally open on one side and locally opening out into waved and crenulated bedding lines, interpretation of which the writer does not attempt, but which probably tell of conditions which if known would indicate the depth of water and other significant conditions of their formation."[2]

On the Belcher Islands these bodies form whole reefs in the more or less silicified limestone of the Belcher series, making up a thickness of over 400 feet (Figs. 9, 10, 11, 12). There appear to be two types, one smaller than the other, but as to whether these should be classed as distinct forms or simply regarded as concretions in different stages of maturity is not yet settled. The fact that the smaller ones form a large, reeflike mass near the top of the algal limestone and near the line where the rocks change in character suggests that they are incompletely developed specimens of the larger type. Both types are spherical to subspherical bodies consisting of concentric layers, and they vary in size from an inch to over fifteen inches in diameter. The larger type is seldom less than four inches, and the smaller seldom more than four inches, in diameter. The larger ones are more regular in form, being much more nearly spherical than the smaller ones, and they also show the concentric lines of growth more distinctly than the smaller ones, which show a tendency to be rather disk-shaped. The distinctly crenulated character of Cryptozoon proliferum is not found in many of these specimens. They are probably more like Cryptozoon steeli.

The concretions consist chiefly of calcium carbonate and can be almost entirely dissolved in cold hydrochloric acid. There is, however, some silica in small grains of various sizes, some chalcedony infiltrated along the lines between the bodies, and in some places a little carbon may be found under the microscope, especially along the surface separating the concentric rings of growth. This

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[1] A. P. Low, *Geol. Sur. of Canada Ann. Rept.*, XIII, Part D, p. 46D.

[2] C. K. Leith, *op. cit.*, p. 240.

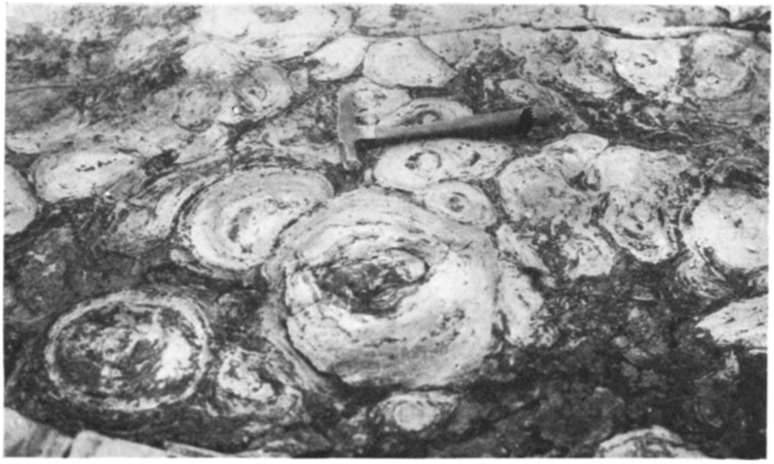

FIG. 9.—The algal concretionary limestones on Tookcarak Island. The largest concretion is about 15 inches in diameter.

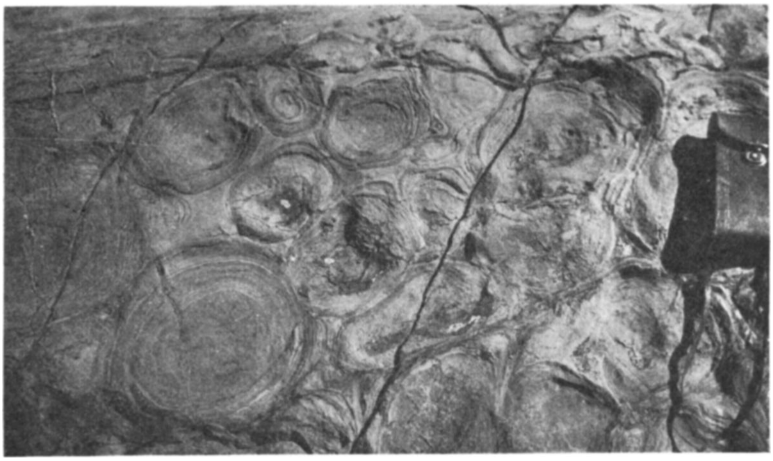

FIG. 10.—Algal concretionary limestone on Tookcarak Island. The largest concretion is 14 inches in diameter.

carbon is left on dissolving the rock in cold or hot acid. No definite cell structure can be recognized in this carbon, but in some of the granules in the calcareous beds of the iron-formation, a little higher up in the series, grains of iron oxide, now replacing the calcareous matter, show such a distribution, size, and

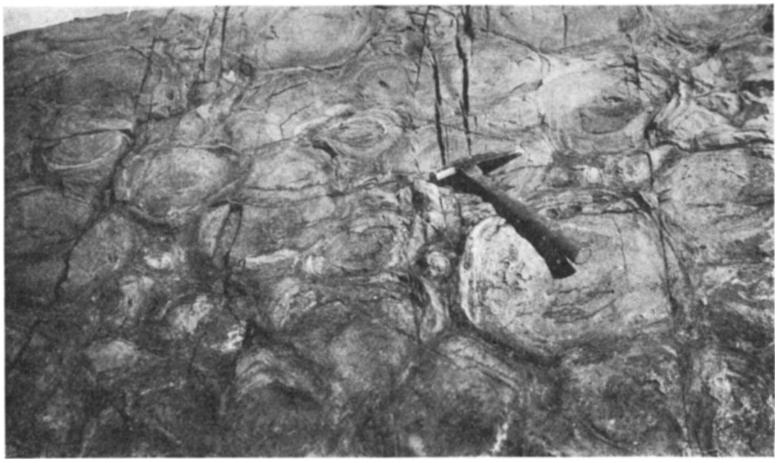

FIG. 11.—Another view of the large type of algal concretions

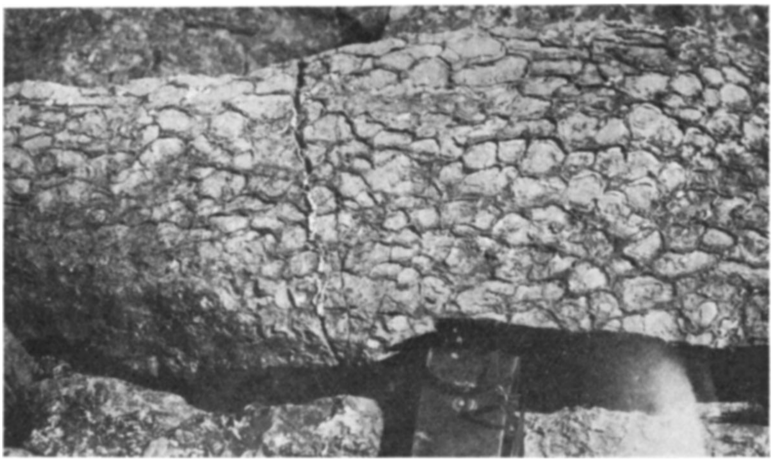

FIG. 12.—The smaller type of algal concretions in the limestone on Tookcarak Island.

arrangement that they seem to indicate the replacement of organic cells.

That these larger concretions are the result of the action of algae, which cause precipitation of calcium carbonate owing to the chemical changes produced in the water by them, there seems to be little doubt. They are very similar to the concretions described from the Algonkian rocks of Montana by Walcott,[1] and the calcareous concretions described by Roddy[2] as now forming in the streams of Lancaster County, Pennsylvania (Fig. 13). Numerous other occurrences of similar deposits have been described by other writers. The two types, large and small, bear certain resemblances to Walcott's *Newlandia concentrica* and *Collenia? frequens*, but they do not seem to be identical with them, and new generic and specific names should be applied.

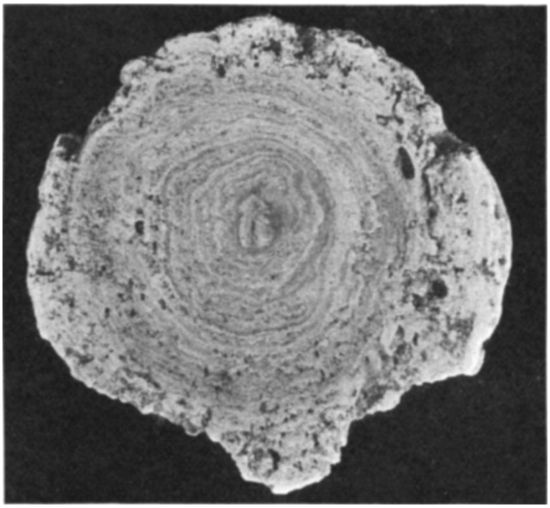

FIG. 13.—Recent algal concretion collected by J. Roddy in Conestoga Creek. Lancaster County, Pennsylvania (2.5 inches in diameter).

As stated above, no definite organic cell structure has so far been recognized in these large concretions, but the replacement of calcium carbonate by iron oxide in some small concretions in this same series of rocks was so suggestive that the attention of Dr. J. Ben Hill, of the department of botany, Pennsylvania State College, was called to them. Dr. Hill very kindly examined them, prepared the accompanying camera lucida sketches (Fig. 14), and the following statement regarding these bodies:

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[1] C. D. Walcott, *op. cit.*

[2] H. J. Roddy, "Concretions in Streams Formed by the Agency of Blue-Green Algae and Related Plants," *Proc. Amer. Phil. Soc.*, LIV, No. 218 (August, 1915), pp. 246–58.

> The specimens in question are generally smaller than the living Cyanophyceae, but are not smaller than the smallest of the living species. In fact, the most striking specimens are well above the lower range of size in the living species. The measurements of the *objects* in the rocks range from 0.5 to 2.5 microns for the smaller forms to 5 and 10 microns for the larger. This is exclusive of the very minute and the very large ones. The shapes of the objects would suggest species in the two classes (Coccogoneae and Hormogoneae). The isolated spherical forms resemble some genera of the Coccogoneae as *Chrococcus* or *Gleocopsa*, and the specimens showing cell-like structures connected to form a filament, some genera of the Hormogoneae as *Nostoc* or *Anoheana*.

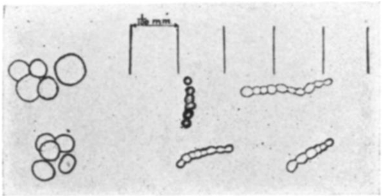

FIG. 14.—Camera-lucida drawings by J. B. Hill of grains of iron oxide resembling replacements of algal cell structures. The accompanying scale indicates the diameter of these bodies.

Although Dr. Hill and the writer both recognized the great difficulty in distinguishing small mineral grains, which often form strings and bunches, from organic structures we feel satisfied that the sizes, shapes, and arrangement are too regular to be the result of simple replacement without some original organic control. A further discussion of these smaller concretions will be found in the section on the iron-formation.

The photographs, thin sections, and two specimens of the concretions were later sent to Dr. M. A. Howe, of the New York Botanical Gardens, and to him the writer is indebted for his kindness in making an examination of these materials. Regarding them Dr. Howe makes the following statement:

> This Hudson Bay limestone is of obviously organic origin, and the organisms contributing to its upbuilding are, it seems to me, in all probability of a vegetal and algal rather than animal nature, though the microscopic structure

shows little or nothing that would justify a student of the recent algae in referring them to a modern genus, family, or class. I infer that the main organism deserves comparison with *Cryptozoon proliferum Hall* from Saratoga, New York, and one photograph is a bit suggestive of Walcott's *Collenia? frequens* as shown in his Plate 10, Fig. 3. Unless more definite structure is revealed by future sectioning it seems to me that about as far as we can safely go with these Hudson Bay fossils is to say that they are *probable* algae.

Another structural feature in the limestones of the Belcher series, and one which may also depend upon organic agencies for its origin, is a remarkably regular and uniform banding, which is due to alternating very fine-grained and coarser-grained layers of limestone, more or less silicified, especially along the bedding planes (Fig. 15). As seen under the microscope some very small fragments of twinned feldspar scattered through the fine-grained layers and grains of quartz are fairly common. In the hand specimen the rock looks more like a cherty quartzite than a limestone, it is so dense and fine-grained. The alternate bands weather more rapidly, producing a ribbed effect. The bands are often extremely regular for considerable distances and usually run from one-half inch to three-quarters of an inch in width. It is suggested that this banding may be due to the seasonal work of low forms of life

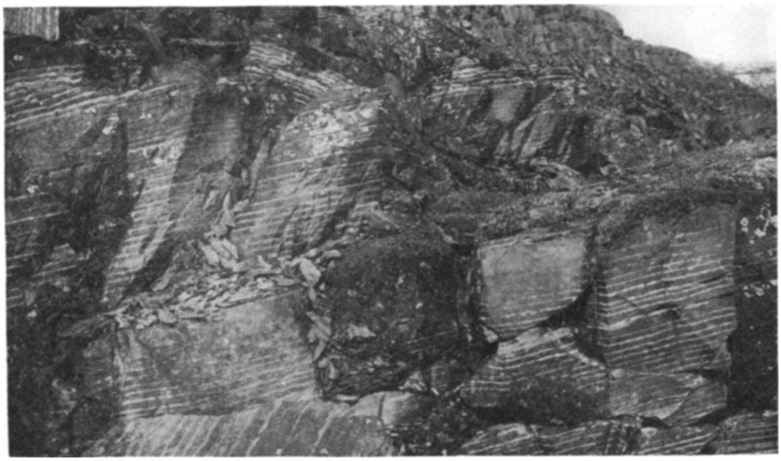

FIG. 15.—Very distinctly banded limestone on Innetallung Island. It is believed that the regularity of this banding may be due in some way to the action of algae.

causing variations in the nature of the deposits made during the different seasons of the year.

THE KEEPALLOO IRON-FORMATION

The term iron-formation is used here as in other writings on pre-Cambrian geology for a group of rocks which vary considerably in composition, but which together contain conspicuously more iron than their associated rocks, and which by natural concentration processes are capable of giving rise to iron-ore deposits.

There is a large body of this formation on the Belcher Islands, and the term Keepalloo has been applied as a local name for it, since it is so well exposed on the peninsula along Keepalloo Sound. It consists of jaspilite, iron carbonate, calcite, probably iron-magnesium carbonate, hematite, magnetite, chert, and greenalite. A section on Keepalloo Peninsula from the quartzite up to the basalt is as follows:

	FEET
a) A mixture of cherty, sandy, jaspery, calcareous granular rock with bands of brownish-weathering shale	54
b) Reddish and brownish fissile shale	17
c) Jaspilite	30
d) Jaspilite with bands of hematite ore	39
e) Jaspilite	46
f) Jasper and bands of lean, hematite ore	10
g) Dull, shaly jasper with bands of bright-red jasper, resembling a felsite and containing cubes of pyrite	43
Total	239

In many of these rocks small granules may be recognized with the naked eye, and they occur mostly in those rocks poorer in iron, lying near the top and bottom of the iron-formation. Their greater abundance in these rocks is no doubt due to the fact that the iron oxides lend themselves less favorably to the preservation of such structures than silica or carbonates, where there is considerable concentration of iron, and also to the fact that when a great deal of replacement occurs original structures are likely to be lost.

A number of thin sections from these rocks were studied, and it was found that in nearly all cases the rocks are made up of granules of various types. A thin section of the red jasper overlying the quartzite and lying near the base of the iron-formation showed dirty-gray granules of a variety of shapes having a maximum size of 1.90 by 1.0 millimeters. They consist of calcite, chert, and iron oxide, the latter as a rule distributed in fine specks through the granules in an unusual manner indicating a probable replacement of organic tissues. It was in this section that the minute algae-like cells, previously described, were found (Fig. 16). Numerous veinlets of quartz following lines of fracture-cleavage indicate the extensive transfer of silica since these rocks were consolidated. These granules indicate a replacement of calcareous granules, in most places at least.

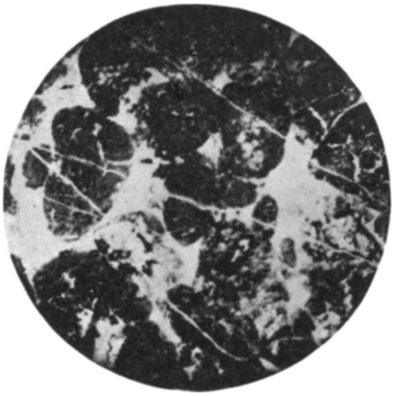

FIG. 16

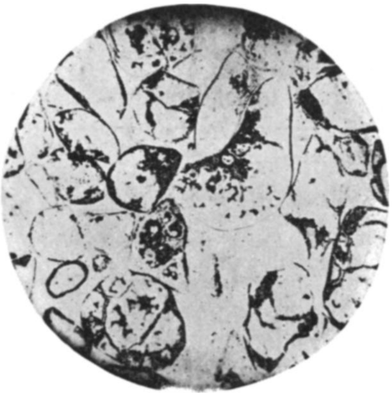

FIG. 17

FIG. 16.—Photomicrograph of granules from the iron formation. These consist of hematite, calcite, and silica, and the groundmass is mostly silica. From these granules the camera-lucida drawings were prepared (×20).

FIG. 17.—Photomicrograph of granules consisting chiefly of silica in which some hematite and magnetite occur, the lighter areas being silica (×20). From the cherty iron formation.

Similar granules in a cherty matrix and carrying considerable magnetite were found in the rock described under *g*) in the section and spoken of as felsitic in appearance.

Another specimen of red jasper with specks of gray opal-like silica was taken from one of the bright-red bands in the iron-formation. It was found to consist of granules of fine-grained chert, opal, and iron oxide. They show a great variety of shapes varying from ovoid, balloon-shaped, ham-shaped, and roughly triangular to nearly spherical. A few are long and narrow and some are curved (Fig. 17). One measured 1.70 millimeters in diameter. Some granules consist of opal, in others the opal is changing to chert by loss of water, and the chert is in turn changing to granules of quartz by crystallization. Some granules consist chiefly of magnetite, some of hematite, and in others a smattering of both occurs throughout the silica. In a number of granules consisting chiefly of iron oxide the grains of silica are arranged in groups, so that they produce under the microscope a cell-like structure strongly resembling what would result if a fragment of a bryozoan were replaced by iron and silica. Its regularity in so many granules is suggestive.

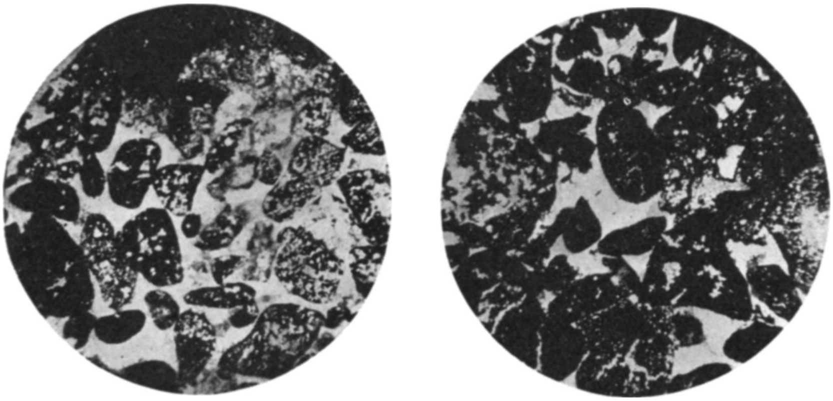
A B

FIG. 18.—A. Photomicrograph showing the hematite and greenalite granules with grains of silica distributed in a cell-like arrangement. The dark concretions are apple green to red and brown. The lighter areas are silica (×20). From the cherty iron-formation.

B. From the same specimen as A.

The most interesting specimen was taken from the siliceous shales in the upper part of the iron-formation, where they underlie the basalt on Kasegalick Lake. In the hand specimen it is a dense, grayish-black to light-gray, cherty rock containing dark, cherty grains. It weathers to a dark, brownish mass. Under the microscope it is seen to be made up almost entirely of granules of various shapes, colors, and sizes (Fig. 18, A and B). In shape they are similar to those described in the last section, ovoid, ham-shaped, irregular, and rarely spherical. In size they vary from 0.14 to 0.91 millimeter in diameter. They are colorless, reddish brown to deep brown, and apple green. The colorless ones consist of very finely granular silica with a matrix of chert and chalcedony. A great deal of calcite is distributed through the section, and one small granule consists entirely of calcite, thus suggesting that all the granules may have been calcite originally.

The green granules vary from apple green through brownish green to dark brown, depending upon the amount of iron oxide which has developed by alteration. They show very little double refraction and no pleochroism except in some places where they are altered to little rosettes of extremely small radiating needles of what is apparently an amphibole, with higher bi-refringence than the chlorites, but lower than actinolite or grünerite. Some granules are largely altered to magnetite, and in others rhombs of limonite indicate the change of siderite to limonite. In many of them the same cell-like arrangement of the quartz grains mentioned in the last section may be seen.

It seems evident that these green granules consist of iron silicate, and of the silicates, thuringite, chamosite, and greenalite commonly found in iron-ore deposits, the characters correspond most nearly to Van Hise and Leith's description of the greenalite granules of the Mesabi Range.[1]

ORIGIN OF THE IRON-FORMATION

From the descriptions given above it is evident that we have on the Belcher Islands an unusual development of large concretions whose origin can only be attributed to organic processes. We have further hundreds of feet of rocks consisting chiefly of minute granules, some of which at least show good evidence of being of organic origin from the widespread occurrence of apparent traces of plant remains in them. If these granules be compared with certain siliceous granules in the Upper Cambrian limestones of central Pennsylvania, which grade into typical oölites, it will be seen that they are very similar and that these Upper Cambrian oölites are associated with abundant cryptozoon fossils. Further, if the various types of oölitic iron ores from the Clinton and Cambrian of America, from the Silurian of Europe, and from the Jurassic of France and England be examined, similar bodies will be found. In fact, so far as the writer's experience goes with slides from the iron-bearing rocks of the formations later than the pre-Cambrian, such concretionary bodies are only found in those rocks which contain other evidence of organic action.

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[1] Van Hise and Leith, "Geology of the Lake Superior Region," *U.S. Geol. Sur. Mon.*, LII (1911), 165.

Although the writer recognizes that low forms of life, such as algae and iron bacteria, are not essential to the formation of oölites[1] and related concretions in all cases, it seems probable that they generally serve as the agents which produce the chemical changes causing precipitation of the calcium carbonate and the iron. This action seems to be due chiefly to the removal of the carbon dioxide from the acid carbonates by the algae, and the oxidation of the iron by the iron bacteria, thus in both instances producing insoluble compounds. The occurrence of vast deposits of oölites and related concretions in certain geological formations, in some instances on different continents during the same period, is also suggestive of the influence of certain organisms which reached a high stage of development at that particular time and caused the precipitation of the iron or other salts. It may also be due to the particular conditions of erosion, which permitted a large amount of any particular kind of salt to be carried to the sea during a certain geological period.

In his monumental works on the origin of the pre-Cambrian iron ores in various parts of the continent Dr. Leith has held firmly to the belief that the bulk of the iron has been supplied directly to the sea as magmatic waters accompanying the great eruptions of basic igneous rock. He advocates this theory very strongly for the iron-formations on the east coast of Hudson Bay.[2] Although the writer readily recognizes the possibility of supplies of iron salts from this source, he cannot see that they have played a rôle at all comparable to the supplies carried into the sea, or into inland bodies of water, in which it seems probable that many of our pre-Cambrian deposits may have been laid down by processes of weathering. The largest known deposits of high-grade iron ore in the world, the Brazilian deposits, do not show direct relation to igneous rocks.[1] The great deposits of Lorraine, the Jurassic deposits of England, and our own Clinton ores show no direct relation to igneous eruptions. Going farther back into the pre-Cambrian rocks, it will be found that the greatest deposits of all, those of the Upper Huronian, show far less direct association with the basic igneous rocks than the smaller deposits of the Keewatin. This may be due to a large extent to the conditions of drainage, which must have been much better developed in the Huronian than in the Keewatin, if we can judge from the topographic features which are likely to have been produced during such a volcanic period as the Keewatin, and from the rocks which we now find making up the Keewatin series.[2] There would be a tendency to deposit small and isolated bodies of iron-formation in the Keewatin, which later, on erosion, might add materially to the Huronian deposits.

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[1] An additional note on "The Oölitic and Pisolitic Barite from the Saratoga Oil Field, Texas," *Science*, N.S., XLVI (October 5, 1917), 342.

[2] C. K. Leith, *op. cit.*, p. 241.

The problem of transportation of the silica and iron has always been a big one unless we invoke the aid of hot water and magmatic solutions. However, the work done on colloids in recent years has aided us materially toward a solution of this problem. It has been recognized by Lacroix that colloids are an important product in the weathering actions which produce laterites, and the authors of a recent paper on the origin of the Missouri cherts state that, so far as they know, silica is transported only in the colloidal form and not as a sodium silicate, since such a form dissociates to form colloidal silica.[3]

The silica set free from the decomposition of basic rocks would be almost entirely derived from the silicates, and it might be retained readily and carried in the colloidal form. The iron would also be in the ferrous form and easily transported. It has generally been considered that practically all the silica in these pre-Cambrian iron-formations has been carried in solution, and that very little of it has been clastic sediment. Experience with many different areas of these rocks shows that there is almost invariably a great deal of quartzite, arkose, or graywacke, distinct products of weathering, associated with the iron-formation, and that these often grade into the jaspers. The distinctly clastic sediments cease, and the cryptocrystalline forms of silica take their places. It scarcely seems reasonable that the deposition of clastic siliceous sediment should be so suddenly cut off in all cases and its place taken by chemical precipitates without a great deal of silt being deposited with the chemical precipitates. While this clastic material cannot now be identified in the jasper and chert, it seems probable that it is there, but indistinguishable because of metamorphism from the finely crystallized silica which makes up the bulk of all these jaspilite formations.

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[1] E. C. Harder and R. T. Chamberlin, "Geology of Central Minas, Geras, Brazil," *Jour. of Geol.*, XXIII, 358–62, 385–404.

[2] In the recent volcanics on the island of Hawaii may be seen almost a complete imitation of the topographic features of certain uncovered Keewatin igneous areas.

[3] G. H. Cox, R. S. Dean, and V. H. Gottschalk, *Studies on the Origin of Missouri Cherts and Zinc Ores.* Bull. 2, Vol. III, School of Mines and Metallurgy, University of Missouri.

Regarding the adequacy of the weathering processes to produce these deposits one has but to observe the great deposits of lateritic iron which have formed, and are continuing to form, in Cuba, India, and other warm countries to be convinced of the efficiency of the weathering process. It is evident that the weathering of iron-bearing rocks is almost constantly in operation, but it is owing to certain chemical and drainage conditions that the iron remains on the land as laterite and is not carried off to the sea or to other bodies of water.

The chemical conditions depend upon two important factors, one being the presence or absence of suitable solvents for the iron and the other the presence or absence of suitable precipitating agents which may throw the iron out of solution before it reaches the sea. That considerable iron which is left on the surface as a lateritic deposit and later washed to lower levels as a detrital deposit is carried in solution is evident from the fact that some of it takes on the concretionary form after being transported from its original location.

From a consideration of the laterites the writer believes that the weathering of the basic igneous rocks would furnish plenty of iron to form the pre-Cambrian iron-formations, and that whether the iron will be transported or left as a residual deposit will depend, not only upon the presence of solvents for the iron, but also upon the presence or absence of precipitating agencies. He agrees with Dr. Leith, however, in not regarding the pre-Cambrian iron-formations as laterites *in situ*, although certain portions of them, especially those portions consisting largely of limonite or hematite, argillaceous materials, and silica, may very reasonably be regarded as lateritic, mechanical sediments more or less assorted. The constituents of the granular portions of the iron-formation and the iron carbonate must certainly have been carried in solution, probably as colloids, and through the aid of carbon dioxide and other agents.

In the case of the ferric and siliceous granules in the Keepalloo iron-formation the presence of calcareous granules suggests that they were the primary granules, and that the iron and silica replaced them on the floor of the body of water in which these sediments were laid down. This is the principle of deposition advocated by Cayeux[1] for some of the oölitic iron ores of France. There may also have been some primary iron-oxide and iron-silicate granules, as advocated by Hayes[2] for the Wabana ores of Newfoundland, and it seems probable that the concretionary character of the ore may be due to the action of low forms of life. The work of Harder[3] and previous writers has shown that the iron bacteria are the important agents in precipitating iron compounds. These bacteria were found by Harder to be present in almost all iron-bearing waters, Spirophyllum and Gallionella, the latter, often mentioned among the algae by previous writers, being found even in underground workings of mines to a depth of several hundred feet. Harder found further that some solutions were kept under anaërobic conditions by passing carbon dioxide through them. In some solutions ferric hydroxide was precipitated, while in others there was no precipitate. The precipitation took place from either ferrous or ferric salts by oxidation.

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[1] L. Cayeux, *Les minerais de fer oölithique de France.* Ministere des Trav. Pub., Paris.

[2] A. O. Hayes, "Wabana Iron Ore of Newfoundland," *Can. Geol. Surv. Memoir 78*, Ottawa, 1915.

[3] E. C. Harder, "Iron Bacteria," *Science*, N.S., XLII, No. 1079, pp. 310–11.

In the article previously cited on the origin of the Missouri cherts[1] it has been demonstrated that the presence of carbon dioxide has a very important effect in precipitating colloidal silica in the presence of calcium carbonate, causing it to be thrown down very quickly. It would therefore appear that in the action of carbon dioxide on colloidal silica and on the processes of the iron bacteria we may have a clue to the cause of the distinct banding in some of our pre-Cambrian iron-formations, provided further studies of these rocks tend to show evidence of the wide distribution of plant life during pre-Cambrian time. The fact that living algae will furnish oxygen to the waters around them and when they decay give off a certain amount of carbon dioxide may cause some seasonal variation in the precipitation of the iron and silica, and thus give rise to the banding in some of these rocks. The distinctness of the banding may later be increased by metamorphism with recrystallization of the minerals and a certain amount of transfer of materials among the bands under the influence of chemical affinity.

SUMMARY

The Belcher Islands, which lie about seventy miles from the southeast coast of Hudson Bay, have recently been brought to the attention of geologists through the discovery on them of large areas of iron-formation. The iron-formation forms part of a thick series of sediments consisting of limestones, shales, quartzites, and graywackes, and this series is intruded by sills and overlain by flows of diabase and basalt, making up a group of rocks which in many respects strongly resemble part of the Animikie and Keweenawan formations of the Lake Superior region. The limestone of this group is, however, very unusual, since it consists of concretions varying from one inch to over fifteen inches in diameter and so strongly resembling some of the modern concretions formed by blue-green algae that there seems to be little doubt that they are of algal origin. They bear some resemblance to Cryptozoon proliferum, but differ from that fossil too much to be placed in the same genus. Their abundance indicates the presence of vast numbers of low plants in the Hudson Bay basin in pre-Cambrian time, since it has been generally agreed among geologists who have seen the same series of rocks on the east coast of the bay that they are pre-Cambrian in age.

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[1] G. H. Cox, R. S. Dean, and V. H. Gottschalk, *op. cit.*, pp. 9–10.

The iron-formation consists of jasper, chert, hematite, magnetite, siderite, and green granules regarded as the iron silicate, greenalite. The chert and hematite are also in concretionary form, and it is suggested that the algae and iron bacteria have been responsible for the precipitation of colloidal silica, hematite, and iron silicate in this granular form, in some places as a direct precipitate on the floor of the basin and in others as a replacement of the calcite granules by the iron compounds.